



## Conclusions of the Bolund Experiment and Blind Comparison

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# Conclusions of the Bolund Experiment and Blind Comparison

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**In corporation with Vestas**

EERA Workshop on Wind conditions - University of Porto, 26-28 January 2011





# Content

1. The Experiment
2. The Blind Comparison
3. Conclusions
4. Bolund's Big Brother?





# Wind Turbines in Complex Terrain

Do the models work here?



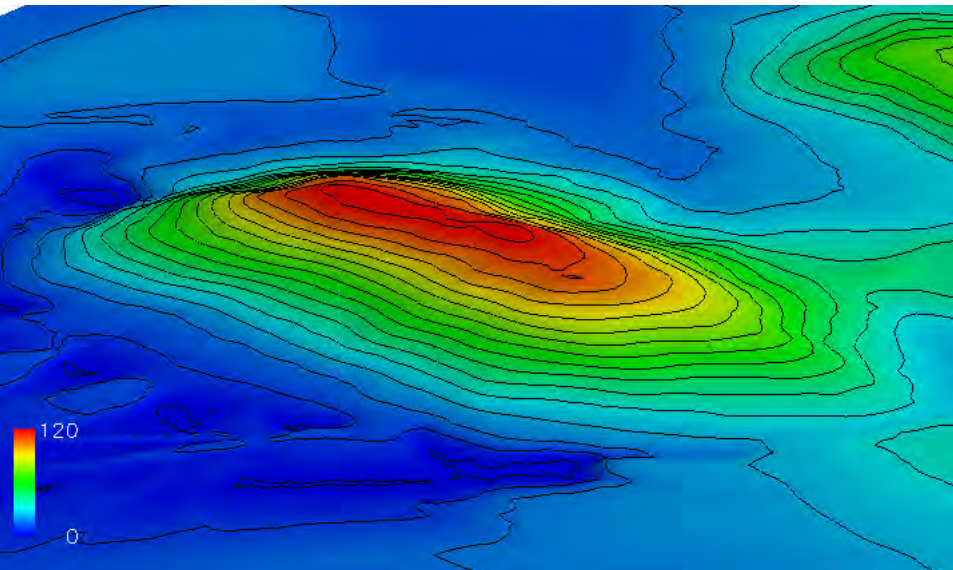


# Askervein and Bolund

Cases for validation of flow models

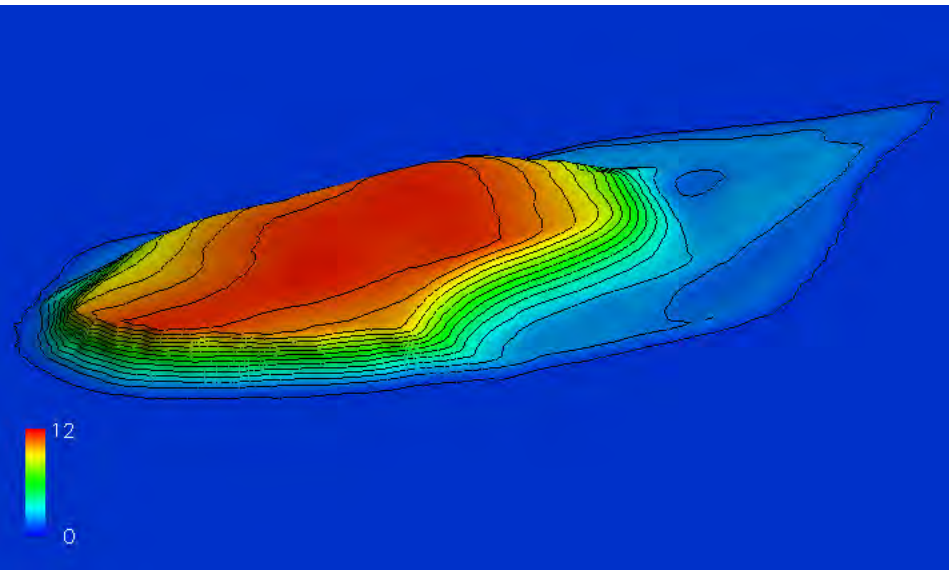
## Askervein Experiment 1983

- Low hill with gentle slope ( $<20^\circ$ )
- Well-defined inflow and
- Uniform roughness



## Bolund Experiment 2008

- Steep escarpment
- Well-defined inflow conditions
- Roughness change



# Askervein and Bolund

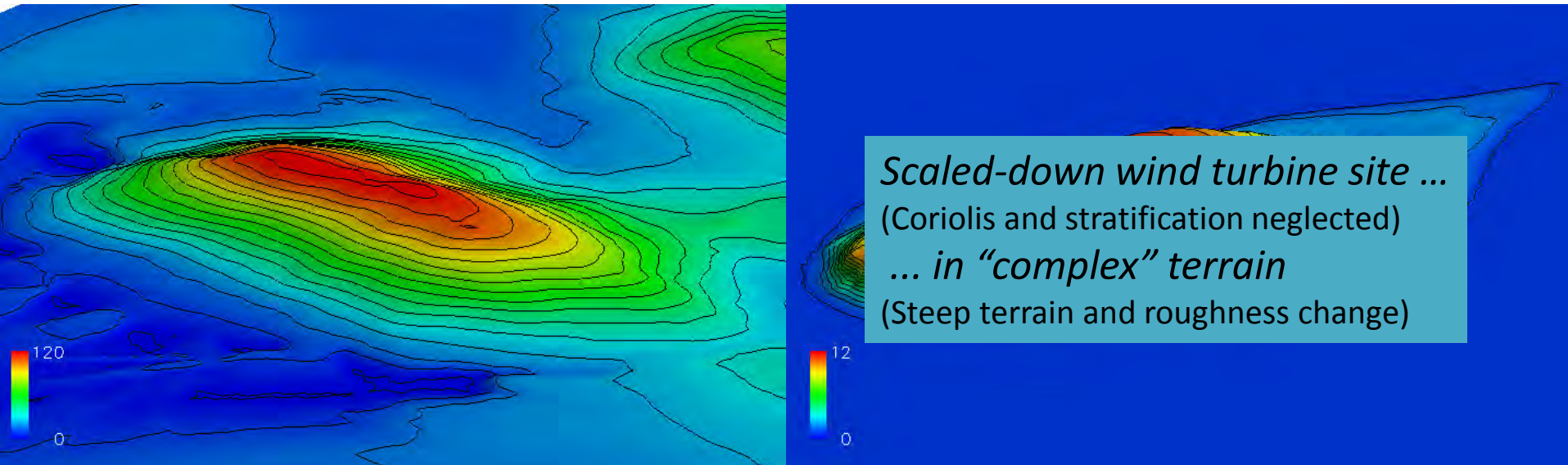
## Scale Effects

### Askervein Experiment 1983

- Stability ( $h=116$  m):  $h \sim L_{MO}$
- Reynolds ( $U=10$  ms<sup>-1</sup>):  $10^8$
- Rossby ( $L=1000$  m): 100

### Bolund Experiment 2008

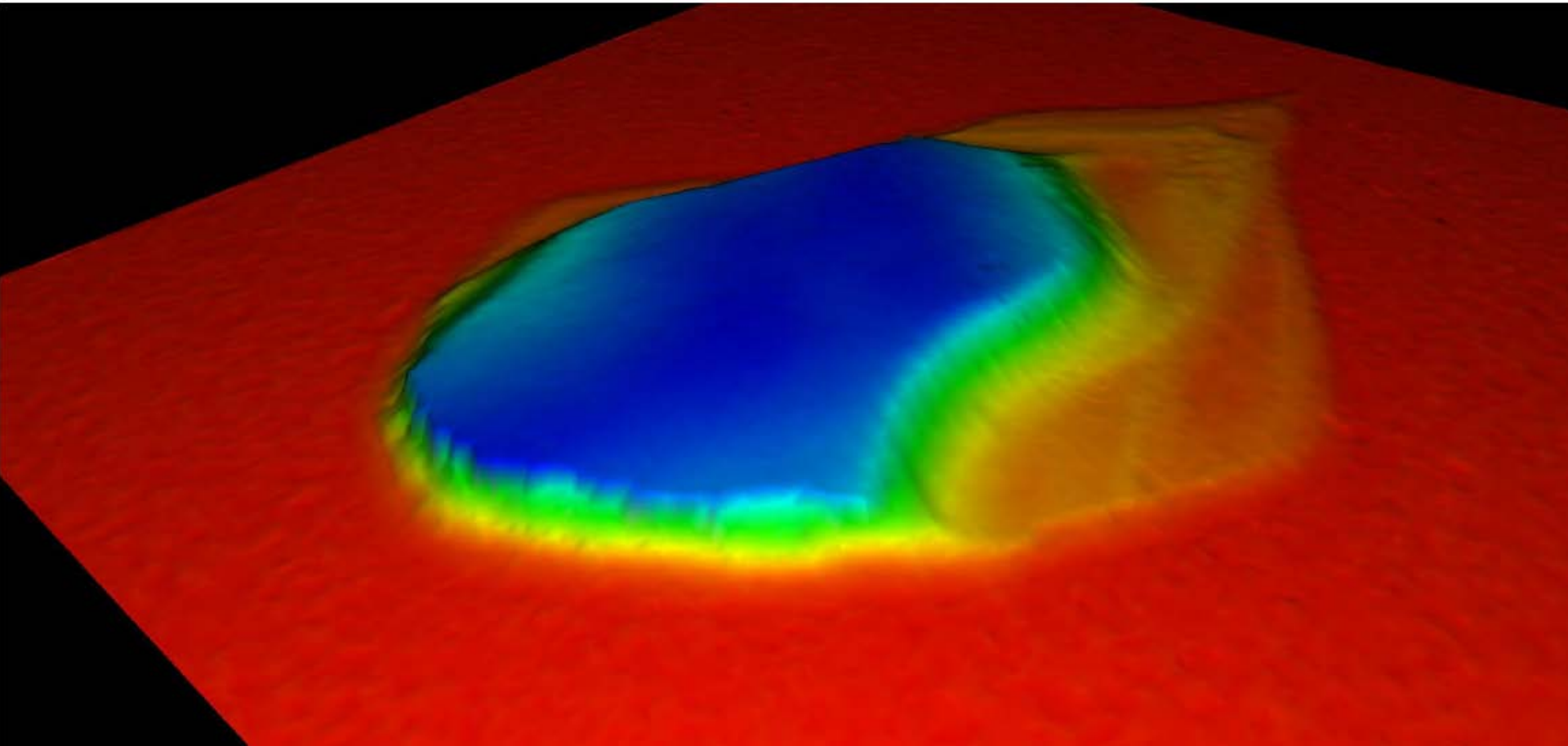
- Stability ( $h=12$  m):  $h \ll L_{MO}$
- Reynolds ( $U=10$  ms<sup>-1</sup>):  $10^7$
- Rossby ( $L=150$  m): 700





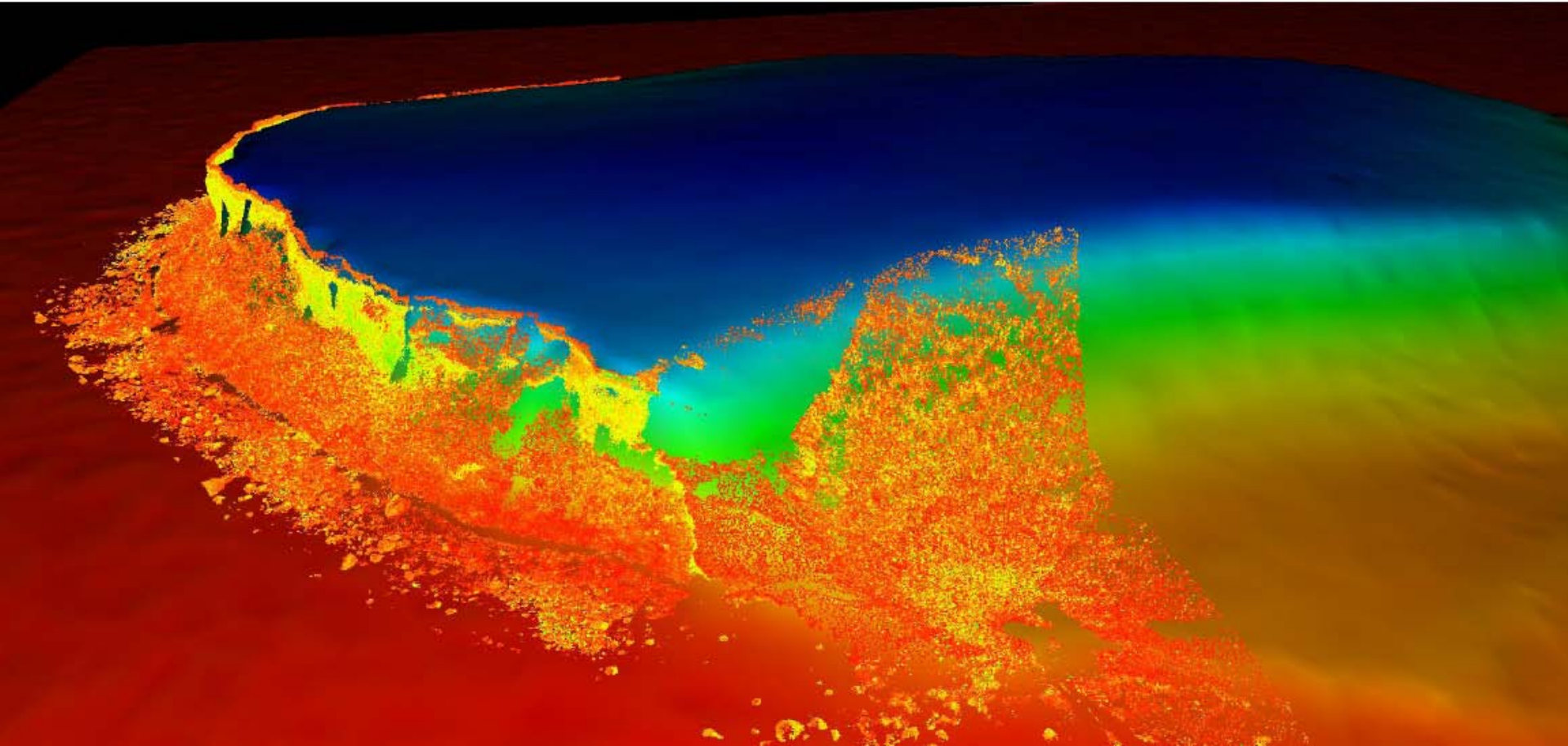
# Height Scanning with laser

Optech Airborne Laser Terrain Mapper:  $\approx 2$  m resolution



# Height Scanning with laser

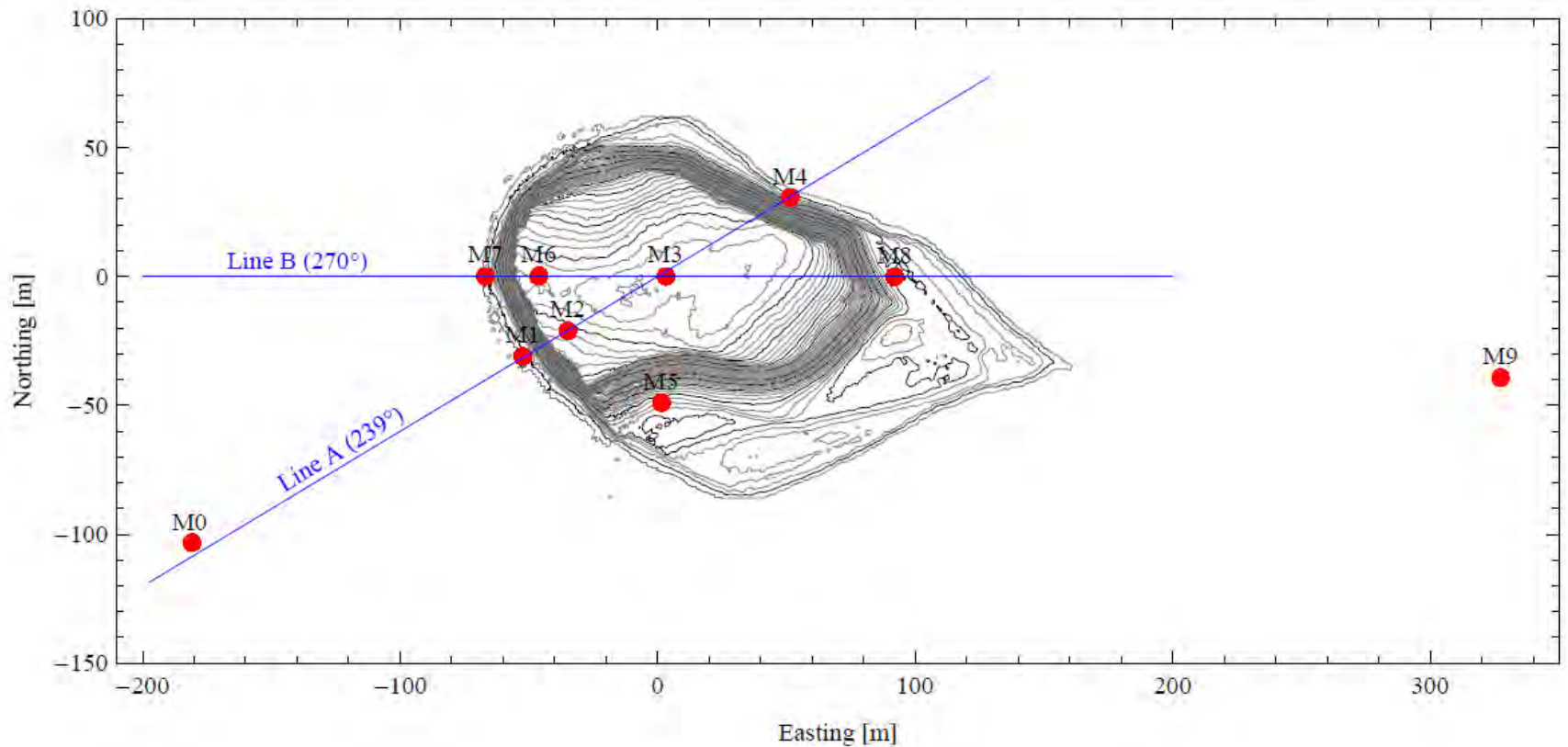
Cliff to steep: additional  $< 0.1$  m resolution scanning applied





# Mast Positions

CFD were used to find the 10 positions



# Erecting the Masts

Since Bolund is protected no machinery could be used





# Instrumentation

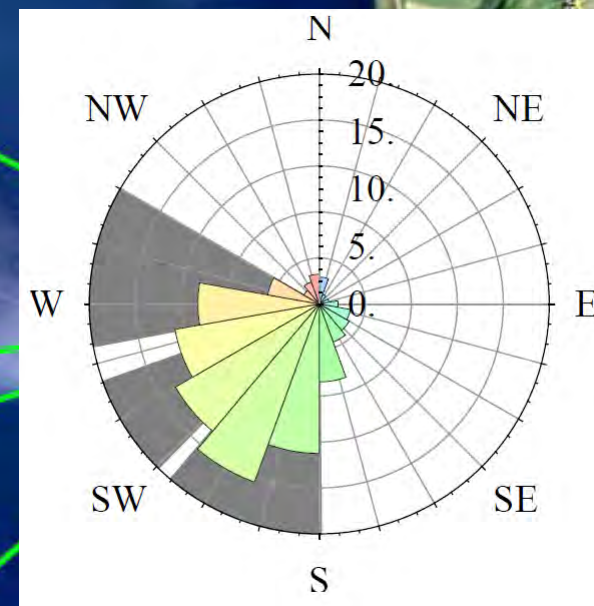
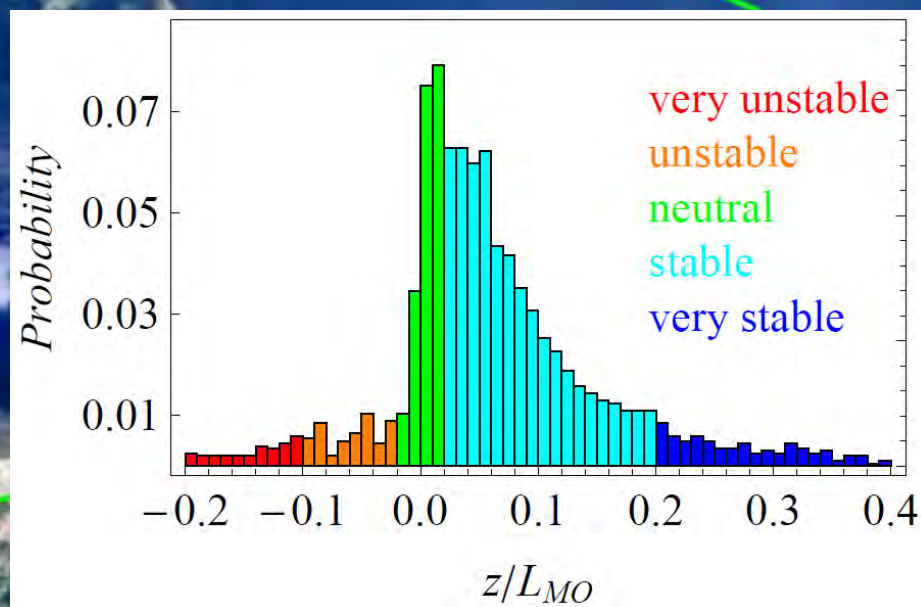
23 Metek Sonics, 2 ZephIR Lidars, 12 Risø Cups



Direct Data Transfer to Risø via RadioLink (20 Hz) and Online Data display

# Upstream Conditions

Sonic data coverage of 92%





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# Purpose of Blind Comparison

- 1. Make The Bolund Data Visible**
  - 2. Evaluate Flow Modeling Accuracy**
  - 3. Standardize Resource Assessment Modeling?**
- 

# Workshop

80 participants joined the workshop





# Blind Comparison

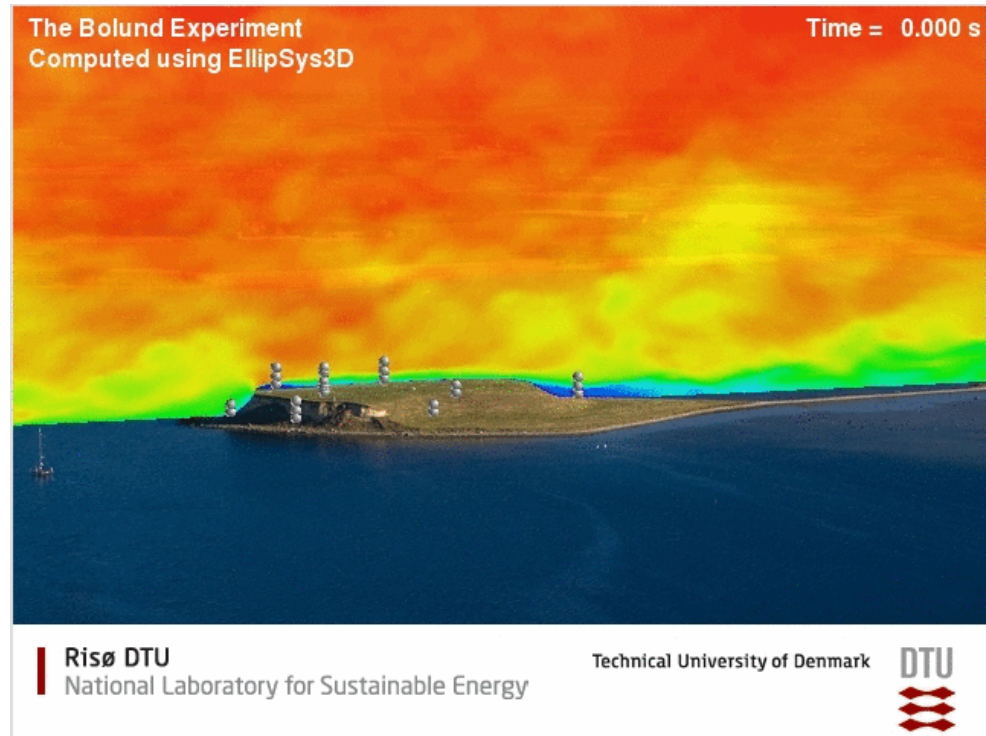
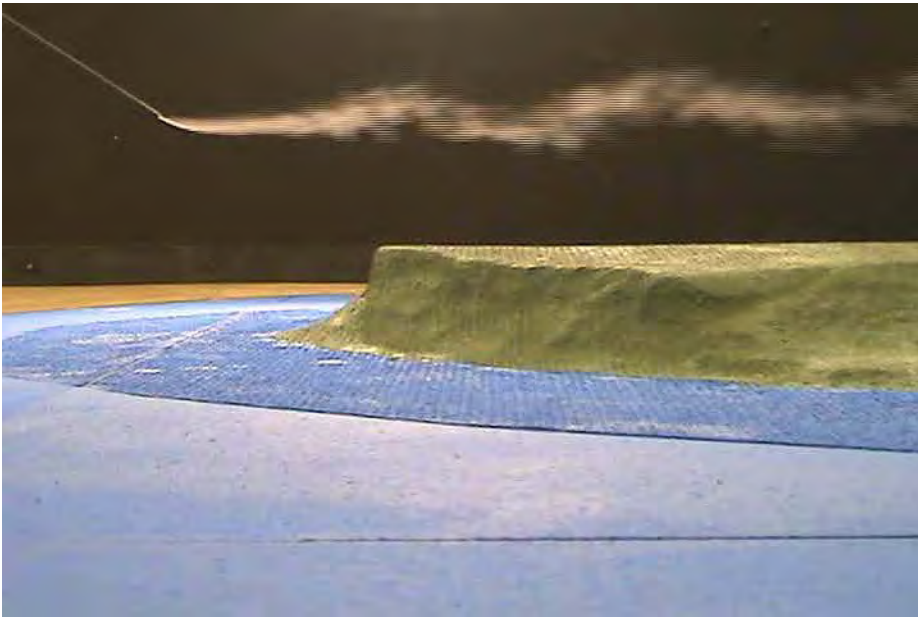
40 companies/universities, 57 model results

## Model types:

- 2: Experimental method
  - 1: Wind tunnel
  - 1: Flow channel
- 11: Linearized flow model
  - 3: WAsP like
  - 5: WAsP Eng.
- 4: No answer
- 40: Non-linear CFD model
  - 6: LES / hybrid RANS-LES
  - 6: RANS 1 eqn.
  - 27: RANS 2 eqn. **24 k- $\epsilon$  models!**

# Model visualization

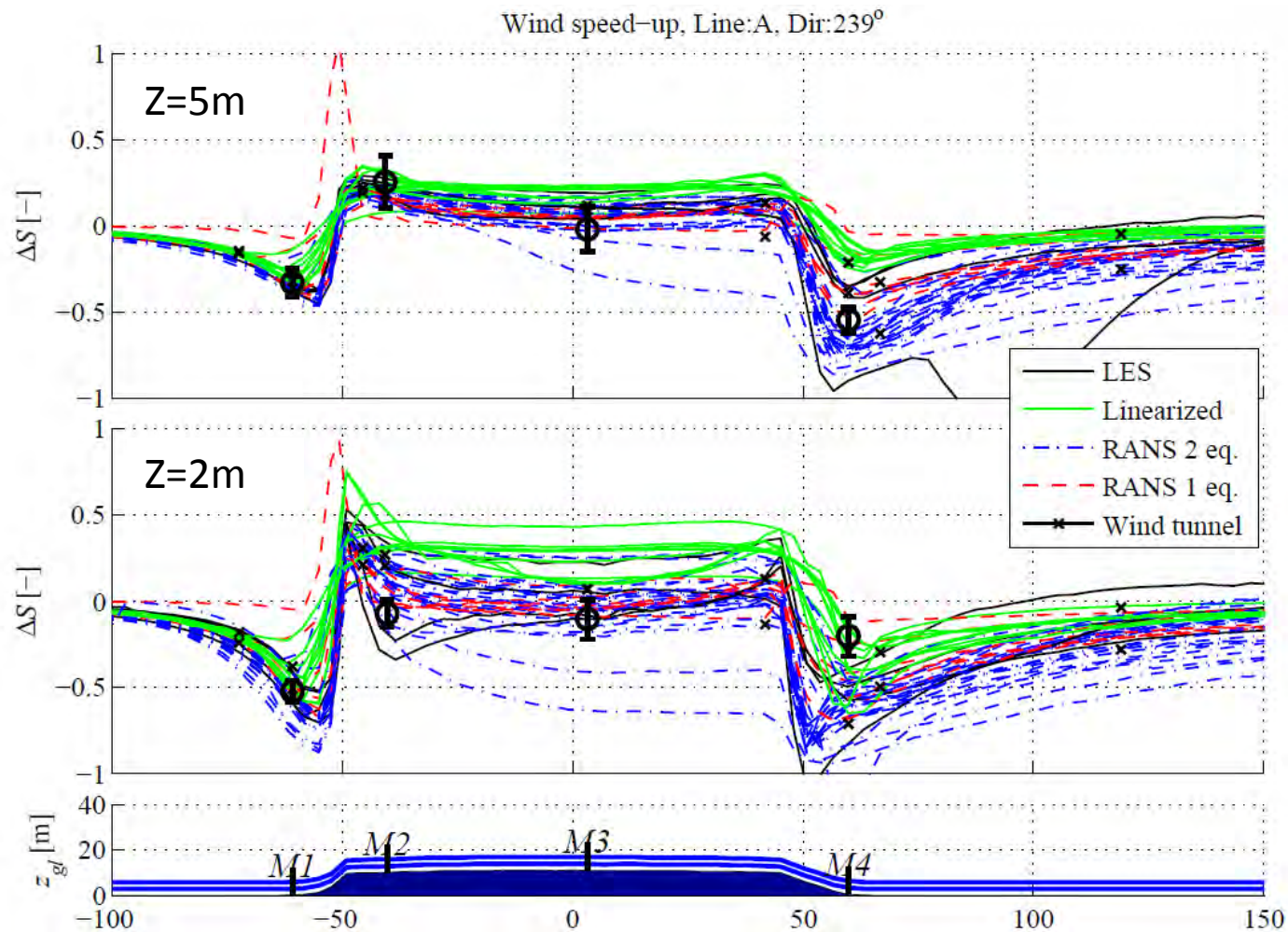
## Wind Tunnel and LES



By: Brad C. Cochran (cppwind.com)

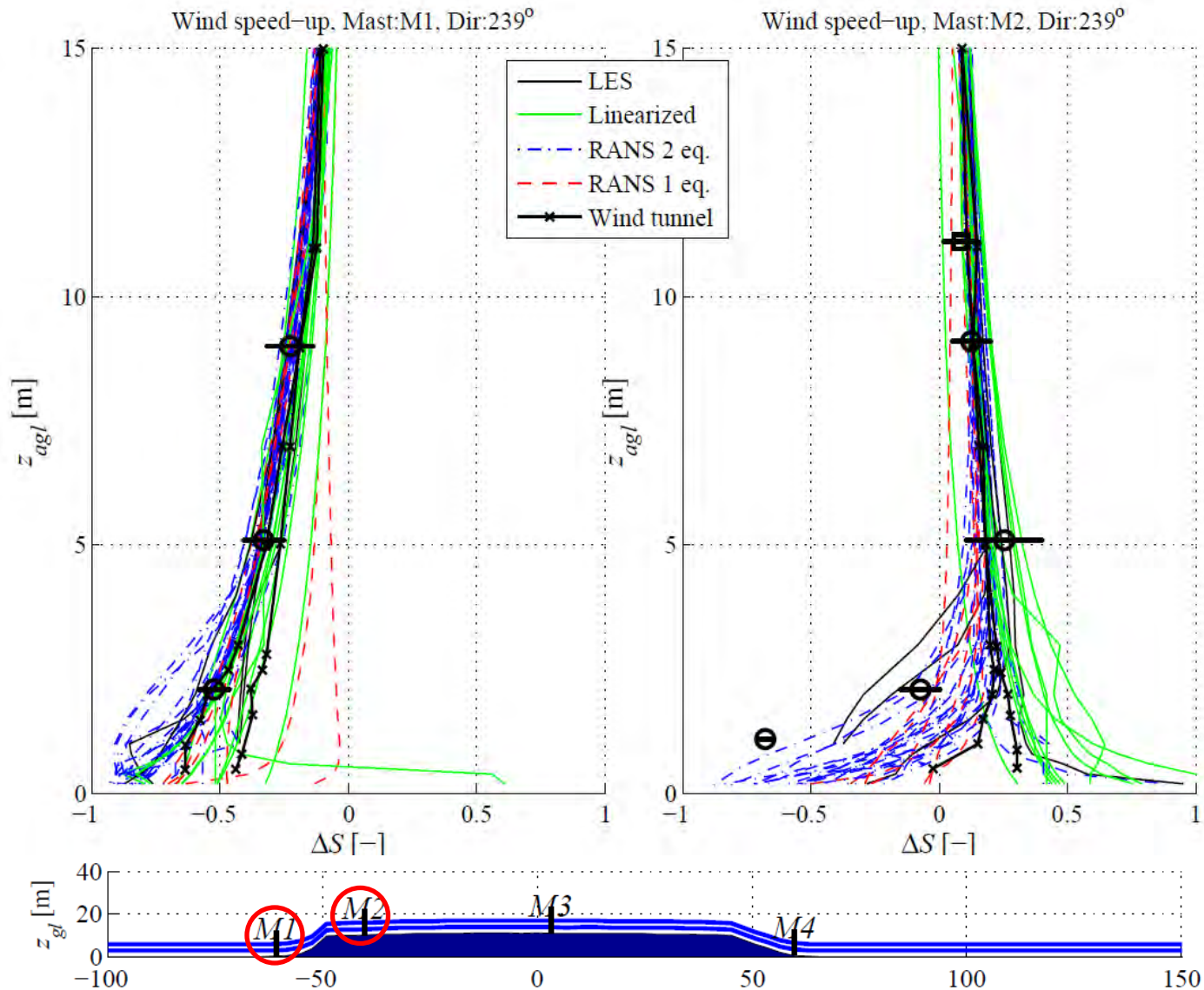


# Speed-up along line A

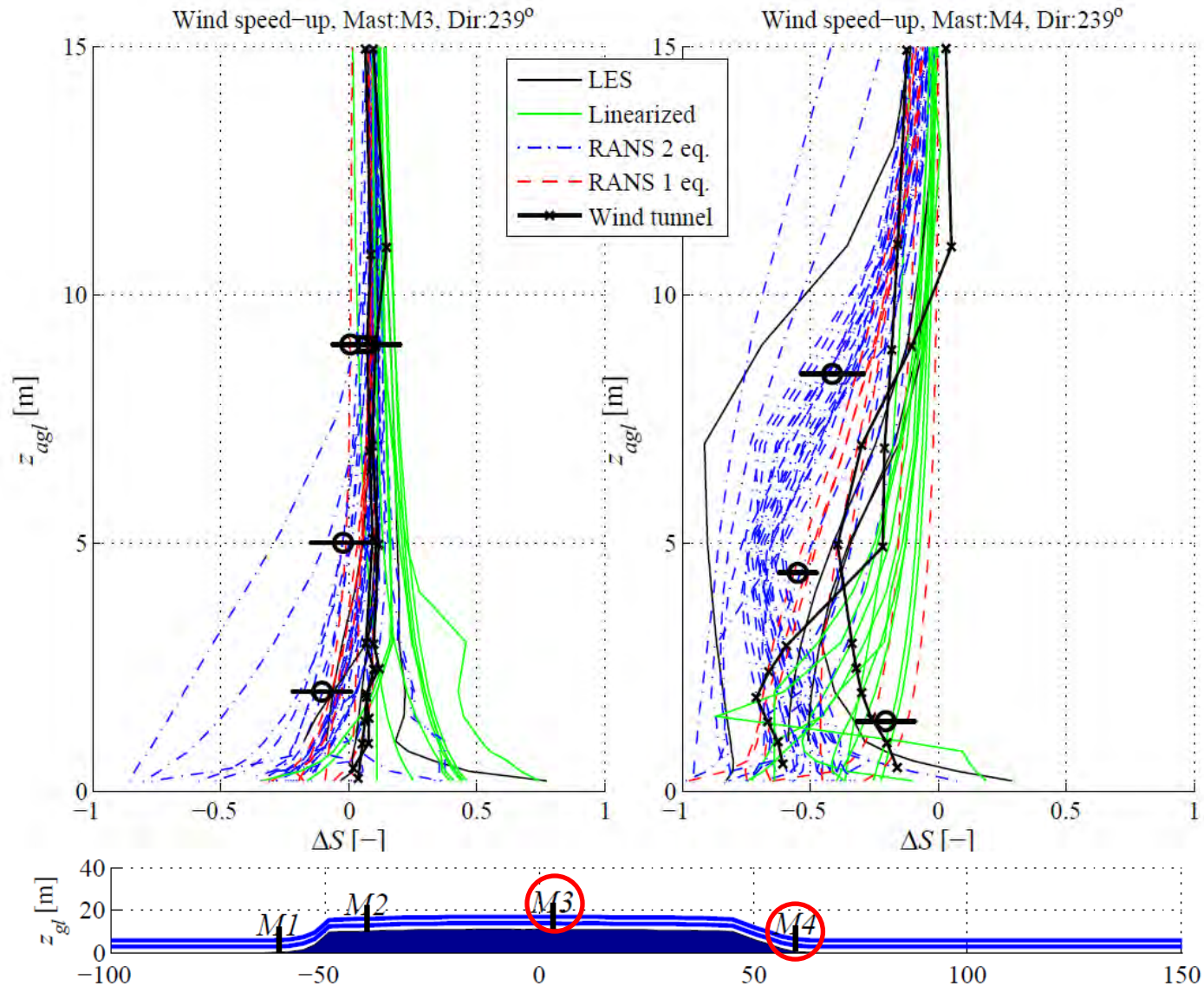




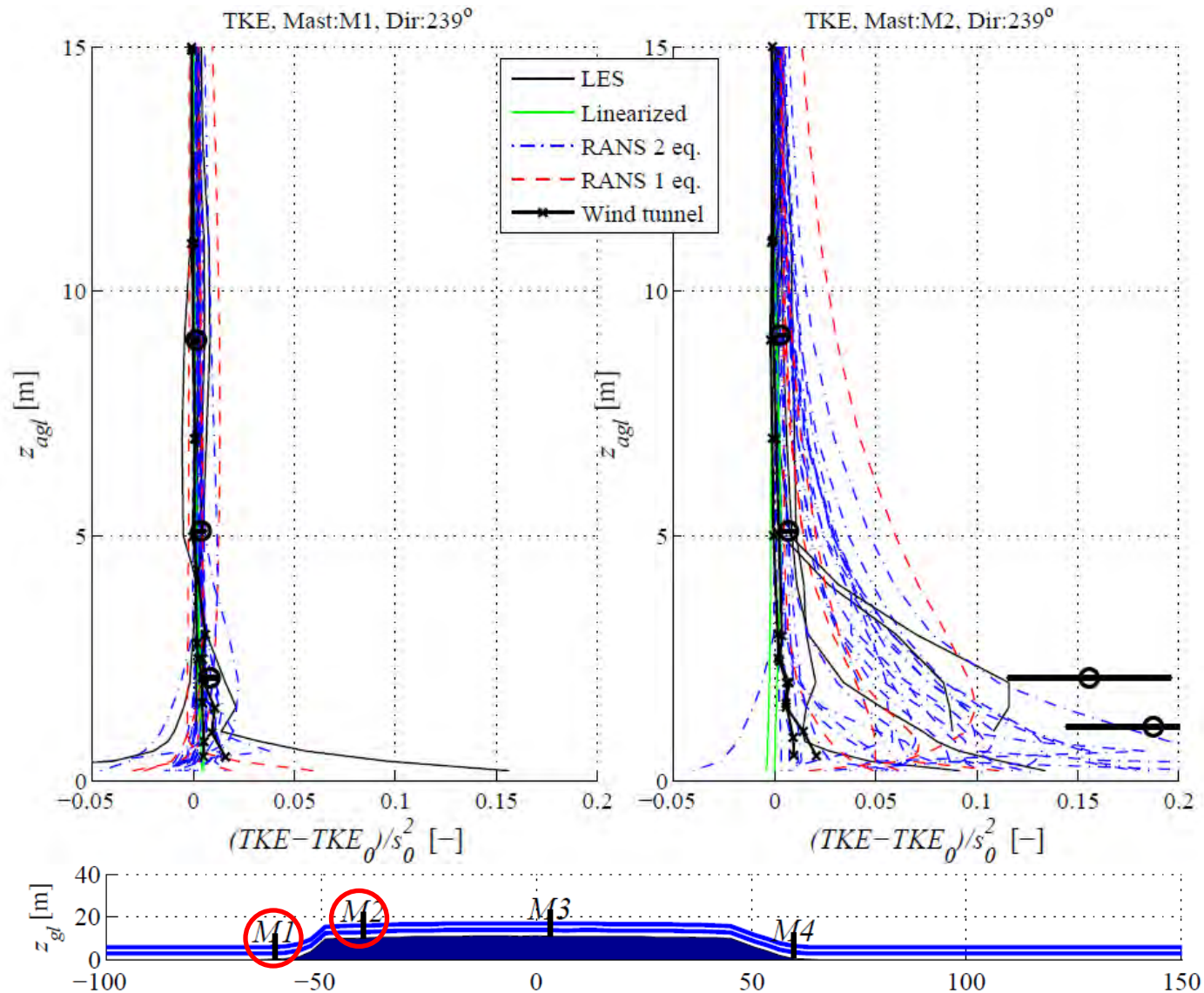
# Speed-up at M1 & M2



# Speed-up at M3 & M4

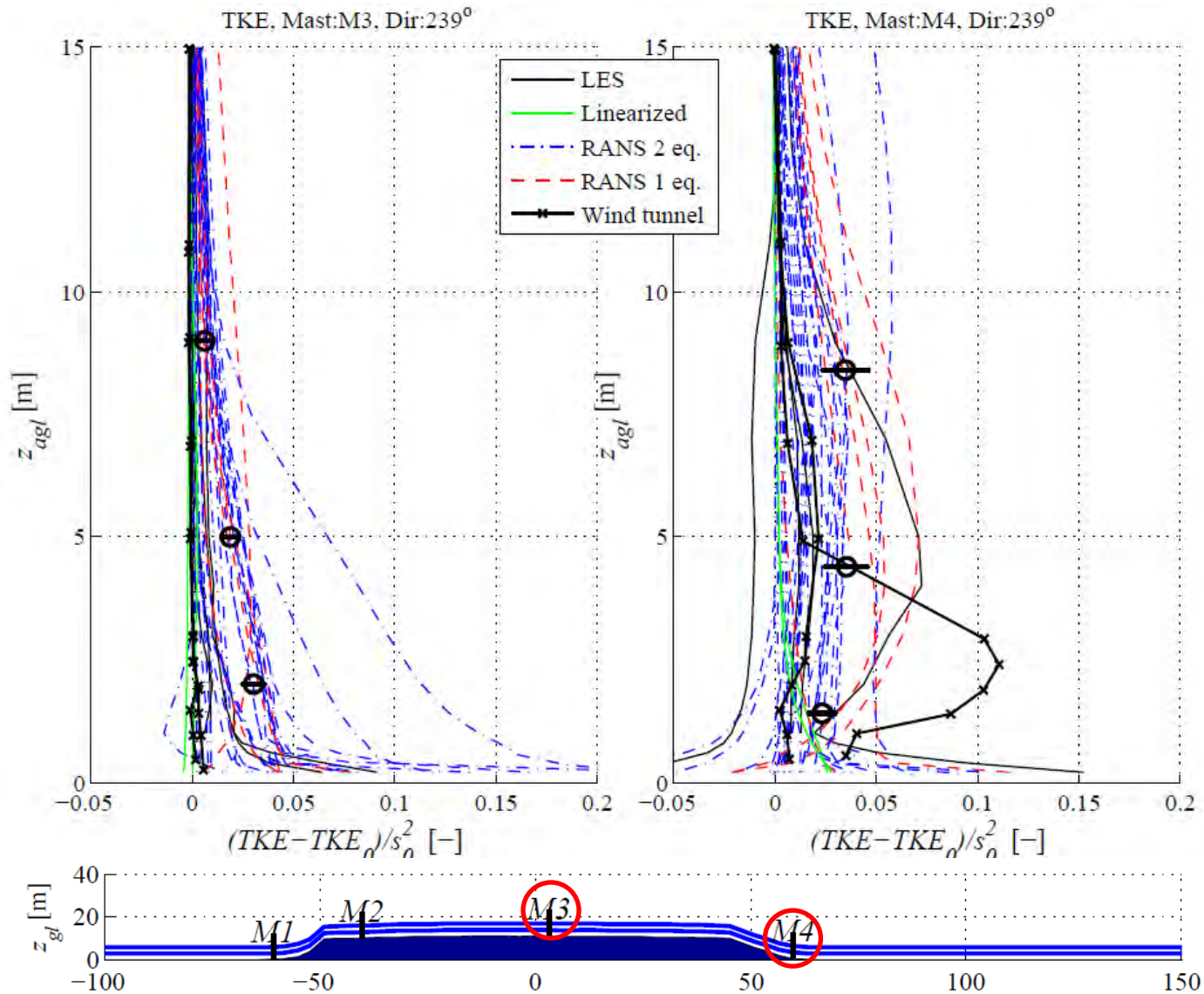


# TKE-up at M1 & M2





# TKE-up at M3 & M4



# Quantifying the model errors

## Speed-up error

- Linear assumptions violated
- LES shows the largest errors
- For  $z > 5m$  the error is 6.5%

$$R_S = 100 (\Delta S_s - \Delta S_m)$$

	Case 1+3
RANS 2 eq.	15.1 (11.4)
Experiment	14.7 (13.3)
RANS 1 eq.	17.2 (13.8)
LES	17.3 (14.1)
Linearised	23.7 (20.6)
All models	17.3

## TKE error

- LES does better than experiment
- Steady RANS performs the best

$$R_{TKE} = 100 \left( \frac{(I_s - I_{0s}) - (I_m - I_{0m})}{I_{0m}} \right)$$

	Case 1+3
RANS 2 eq.	47.0 (29.9)
LES	48.0 (41.6)
RANS 1 eq.	44.7 (42.7)
Experiment	61.4 (59.4)
Linearised	76.7 (71.4)
All models	49.5



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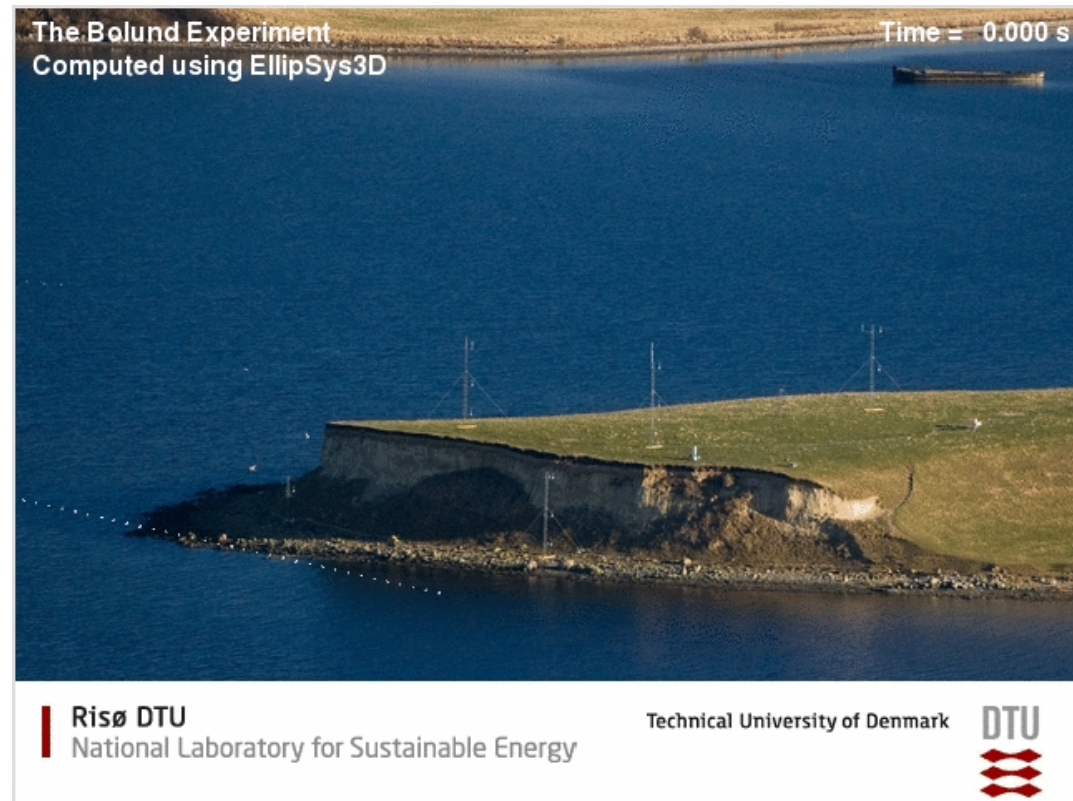




# Conclusions

## The Experiment

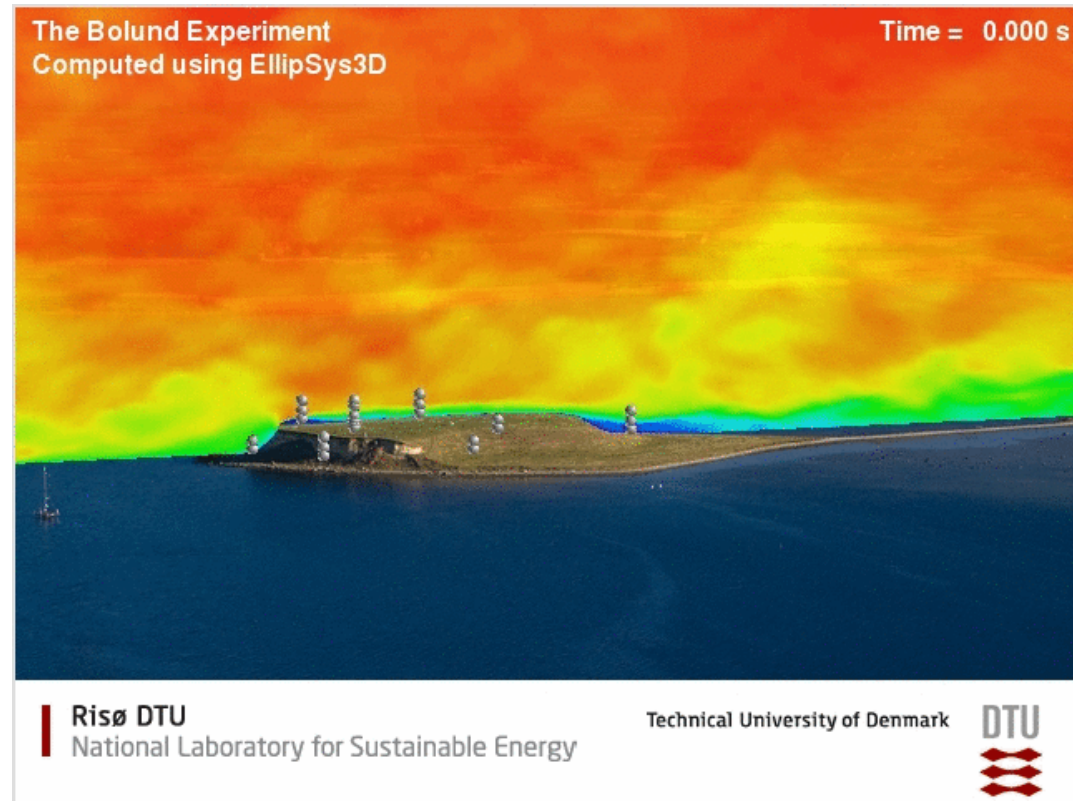
1. Instrumentation and data acquisition worked well.  
Proximity to Risø – convenient.
2. We have successfully captured the gross features of flow over a steep hill.
3. Should we do it over again:  
only measure along one line,  
but more heavily instrumented.



# Conclusions

## The Blind Comparison

1. Recommendation: RANS  $k-\epsilon$  is today's main workhorse, LES has not matured yet.
2. 10% error on speed-up and 20% on TKE is what to expect in complex terrain?
3. 7 diff. CFD solvers in top 10:  
The user is more important than the solver.





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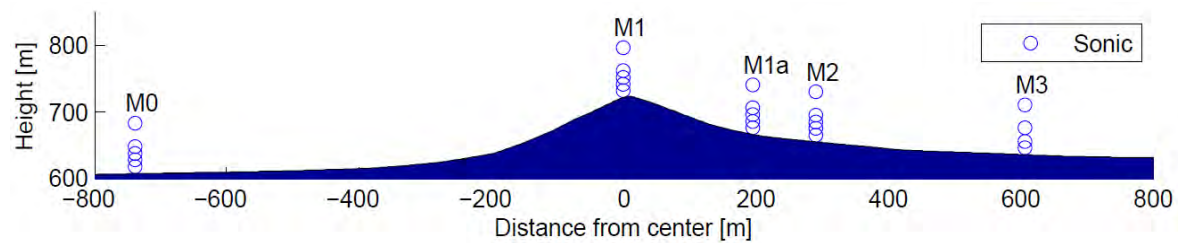




**Benakanahalli**

# Benakanahalli

Results coming up!





# Thank You!



Risø DTU  
National Laboratory for Sustainable Energy

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**Vestas**